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A CLIMATOLOGICAL ANALYSIS OF TWO YEARS OF ROUTINE TRANSOSONDE FLIGHTS FROM JAPAN¹

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ABSTRACT

A climatological analysis is made of Navy-sponsored 300-mb. and 250-mb. constant-level balloon (transosonde) flights launched from Iwakuni, Japan, between September 1957 and April 1959. Since the transosonde naturally provides information in a Lagrangian frame of reference, treated are the trajectories and trajectory dispersion, the magnitudes and periodicities of the velocity and ageostrophic velocity components derived from the trajectories, and the separation between pairs of transosondes as a function of time after their release. In addition to the research benefits, the usefulness of transosondes in providing routine upper-wind data over the oceans is pointed out.

1. INTRODUCTION

Between September 1957 and April 1959, the United States Navy launched transosondes on an operational basis from the Naval Air Station at Iwakuni, Japan. A previous article [1] gave some preliminary results based on the first 6 months of transosonde operation. The purpose of this article is to discuss the more purely climatological results obtained from the full 2 years of operational transosonde flights.

2. THE TRANSOSONDE SYSTEM

The transosonde balloon in use between 1957 and 1959 was 40 feet in diameter and had a volume of about 34,000 cubic feet. The natural floating level of this non-expandable balloon was determined by the balance between buoyancy force (a function of environmental temperature) and the total weight of the system. Owing to the continual loss of helium through the skin of the balloon, the transosonde could be maintained at constant elevation

only by means of a ballast system activated by a barograph. Of the 700 pounds carried to 300 mb. by this balloon, over 400 pounds consisted of ballast. A tendency for the natural floating level of the transosonde to rise as ballast was dropped, was counteracted in 1958 by the addition of a fan which mixed air with the helium within the balloon and thus reduced the lift. With the addition of the refinement, the transosondes seldom deviated more than 1000 feet from their prescribed flight altitude.

For the purpose of telemetering information, each transosonde was equipped with a 50-watt transmitter which operated for 15 minutes every 2 hours at alternate frequencies of 6, 13, and 19 megacycles per second. The transosonde position was determined by means of radio direction finding (RDF) bearings on these signals. This positioning was carried out by 20 RDF stations of the Federal Communications Commission located within the United States (including Alaska and Hawaii) and by the two RDF networks of the U.S. Navy in the Pacific Ocean area. The bearings taken by individual RDF stations were analyzed in Washington, D.C., and Pearl Harbor, Hawaii, and a most probable transosonde position was determined to the

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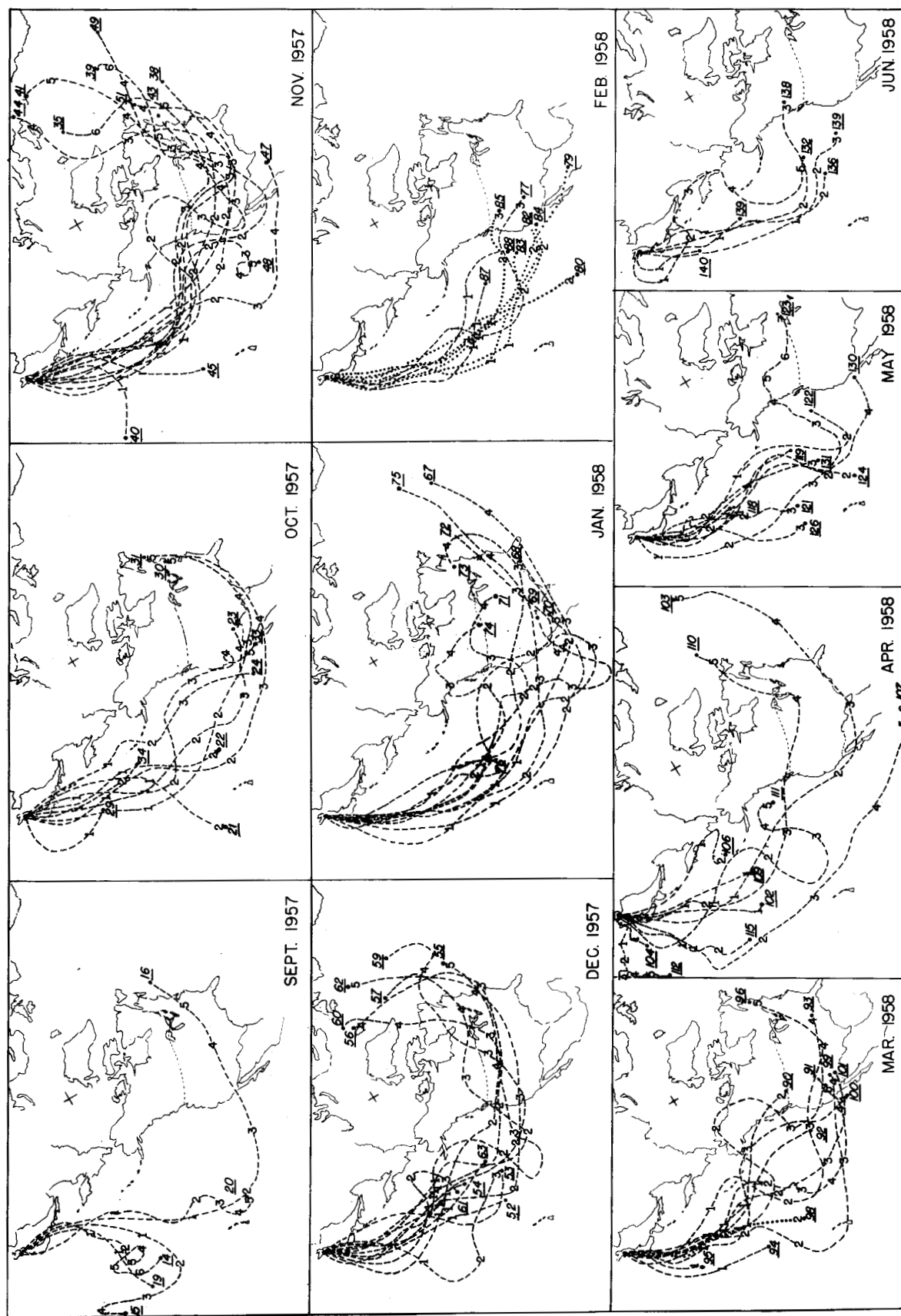


FIGURE 1.—Transosonde trajectories, for flights of one or more days duration, from September 1957 to June 1958. Dashed trajectories represent flights at 300 mb., dotted trajectories flights at 150 mb. The underlined numbers at ends of trajectories are flight designators, while numbers along trajectories indicate days elapsed after transosonde release.

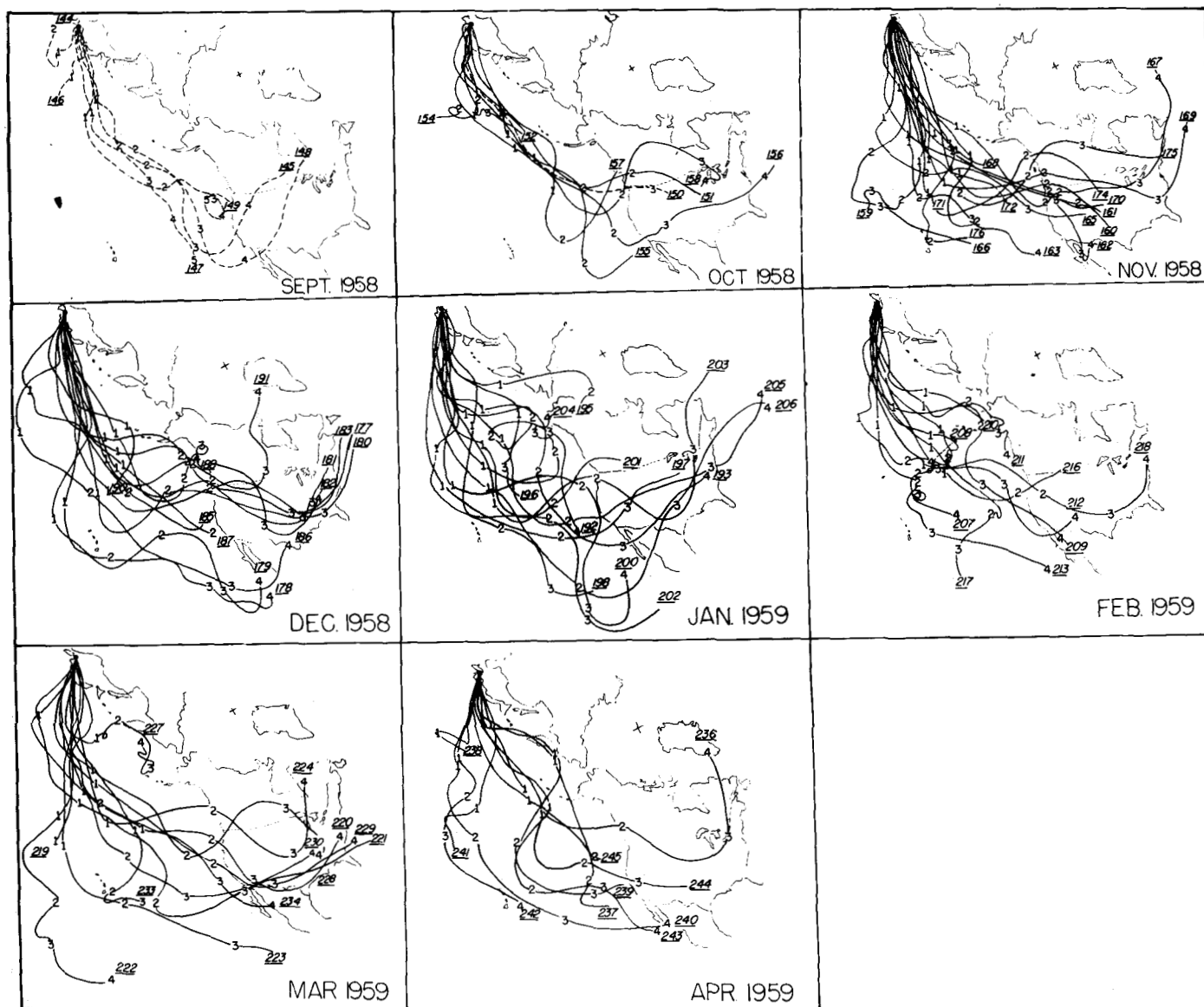


FIGURE 2.—Transosonde trajectories, for flights of one or more days duration, from September 1958 to April 1959. Dashed trajectories represent flights at 300 mb., solid trajectories flights at 250 mb.

nearest 0.1 degree of latitude and longitude. In addition, a rating of accuracy was given each fix based on the area of intercept of the bearings. All calculations of the wind and derived parameters, presented in this paper, are based upon the distance and direction traveled by the transosondes as a function of time, as determined from sequential transosonde positions obtained from the RDF networks.

3. TRAJECTORIES AND TRAJECTORY DISPERSION

Figures 1 and 2 show the trajectories of those transosonde flights which were tracked and positioned by the RDF networks for one or more days. The flights at 150 mb. during February 1958, served to test the suitability of the transosonde system for flights at levels where, in the foreseeable future, there would be no interference with commercial jet aircraft. The change in the usual transo-

sonde flight level from 300 mb. to 250 mb. in October 1958 was brought about by a similar change in the pressure surface analyzed by the National Weather Analysis Center (NAWAC).

It is seen from figure 1 that in November 1957, flight 44 was over Great Britain 4 days after release from Japan, yielding an average speed along the trajectory of 105 knots. Because of the rapid eastward movement of the transosondes during November 1957, and the complaints of certain nations with regard to overflying Eurasia with such balloons, the flight duration during the winter months of 1957-58 was pre-set at 5 days, even though flights of 7 days duration were quite feasible. During the winter of 1958-59 the transosonde flights were limited to 4 days duration in order to avoid interference with the activities of commercial jet aircraft over the Atlantic Ocean. Of

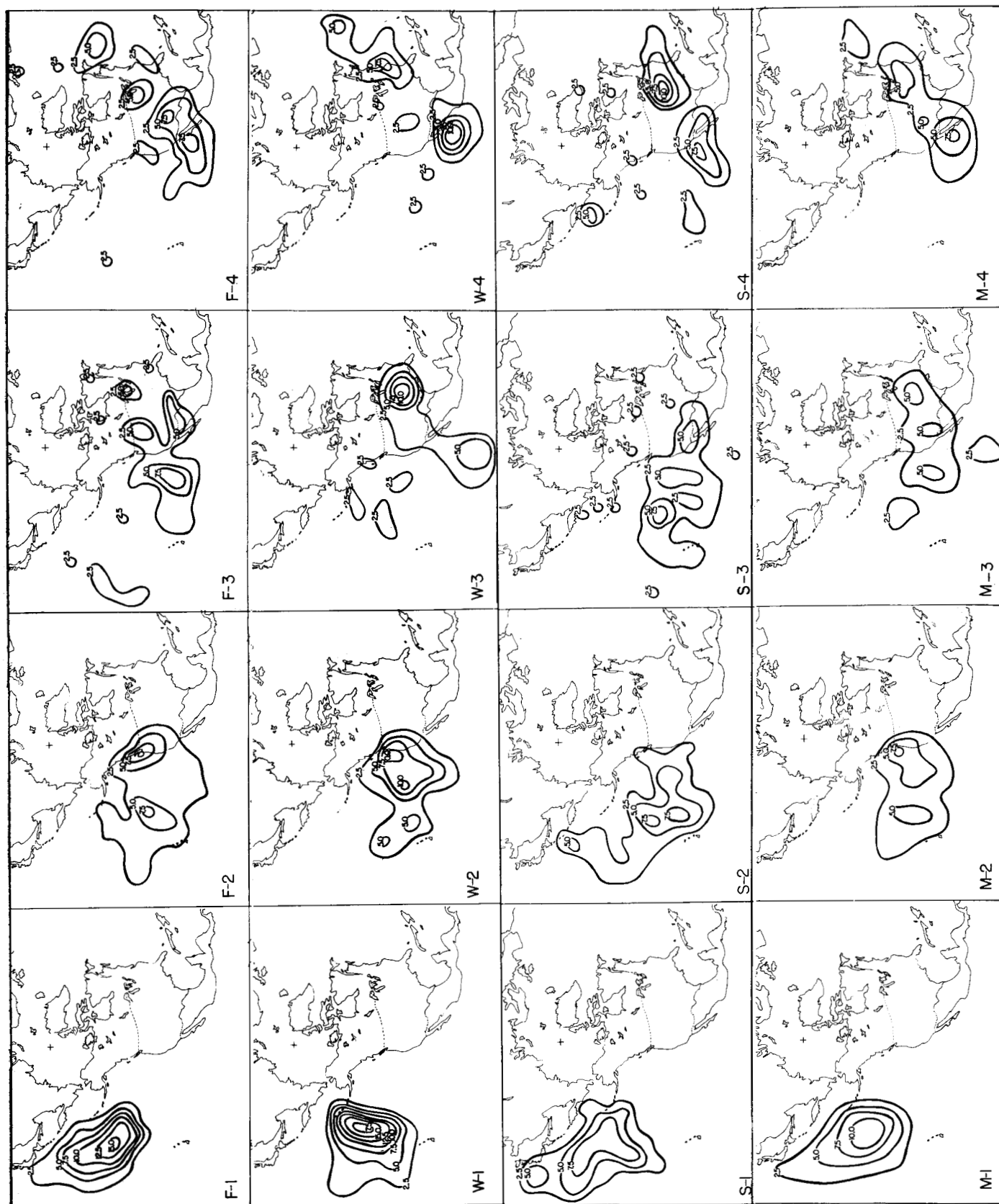


FIGURE 3.—Percentage of transondes released which were located within 10-degree latitude-longitude "boxes" a given number of days after release for fall (F), winter (W), spring (S), and the mean (M) of all flights.

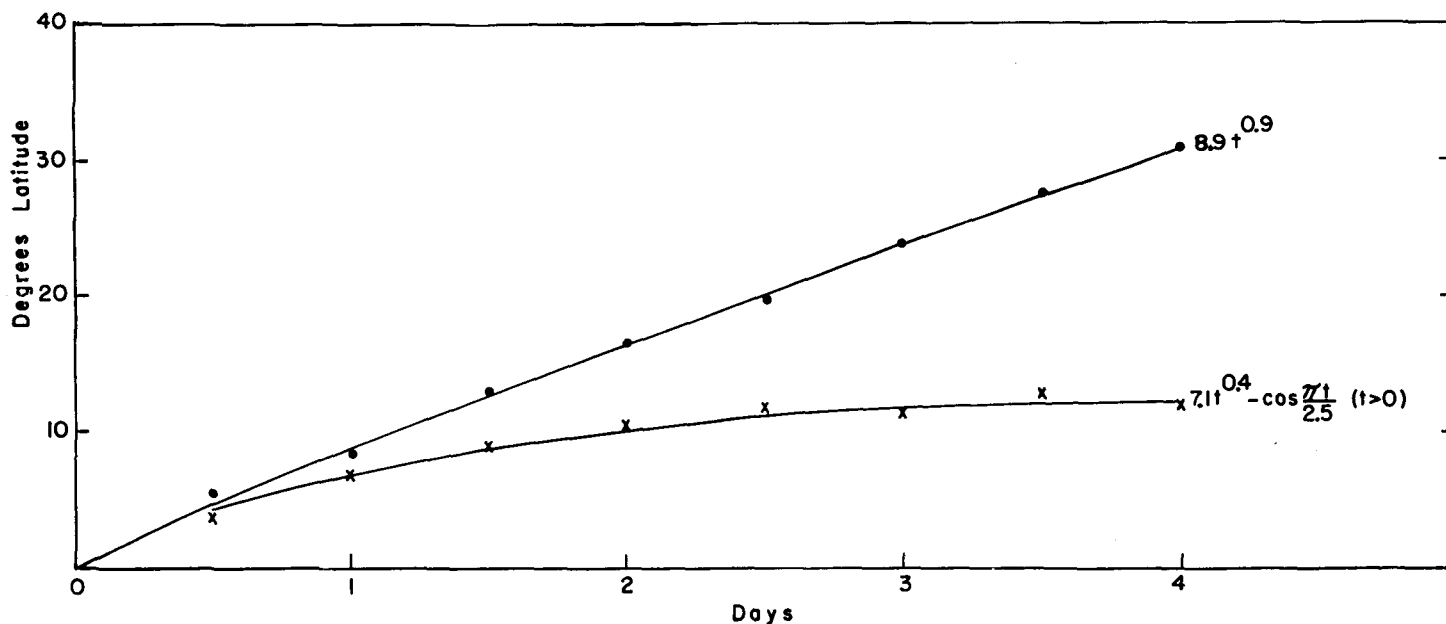


FIGURE 4.—Mean latitudinal (crosses) and longitudinal (dots) standard deviations of position as a function of time after transosonde release for all 1957–1959 flights of four or more days duration. The lines represent the fit of the indicated analytic expressions to the observed values (t in days).

the 230 transosondes released during these 2 years, 179 were tracked and positioned by RDF stations for at least 1 day, 152 for at least 2 days, 116 for at least 3 days, and 83 for at least 4 days.

Figure 3 shows the (smoothed) percentage of transosondes released which were located within 10° latitude-longitude “boxes” from 1 to 4 days after release from Japan. In the mean for all flights, the maximum percentages are located near 180° longitude 1 day after release and just to the west of the State of Washington 2 days after release. Three days after release, in the mean for all flights, the band of maximum percentage extends from 140° W. to the Mississippi River, while 4 days after release the maximum percentages are centered over the State of Kentucky and an area somewhat to the west of Baja California. One would judge from figure 3 that in all three seasons there are two dominant circulation patterns over the northeastern Pacific and North America, one of which carries the transosondes eastward across the United States while the other carries the balloons into a transosonde “graveyard” to the west of Baja California. This tendency for transosondes to congregate near Baja California, is of practical importance since many storms influencing southern California and Arizona are difficult to position owing to the lack of conventional upper-air data in this region. Also of interest in figure 3 is the concentration in transosonde position 1 day after release during winter which indicates the steadiness of the wintertime winds over and to the east of Japan.

Values of the latitudinal and longitudinal standard deviation of transosonde position a given number of days after release were determined by direct evaluation of the

root mean square of the latitudinal and longitudinal distances between mean and individual flight positions for all 300-mb. and 250-mb. flights of four or more days duration. Figure 4 shows these latitudinal (crosses) and longi-

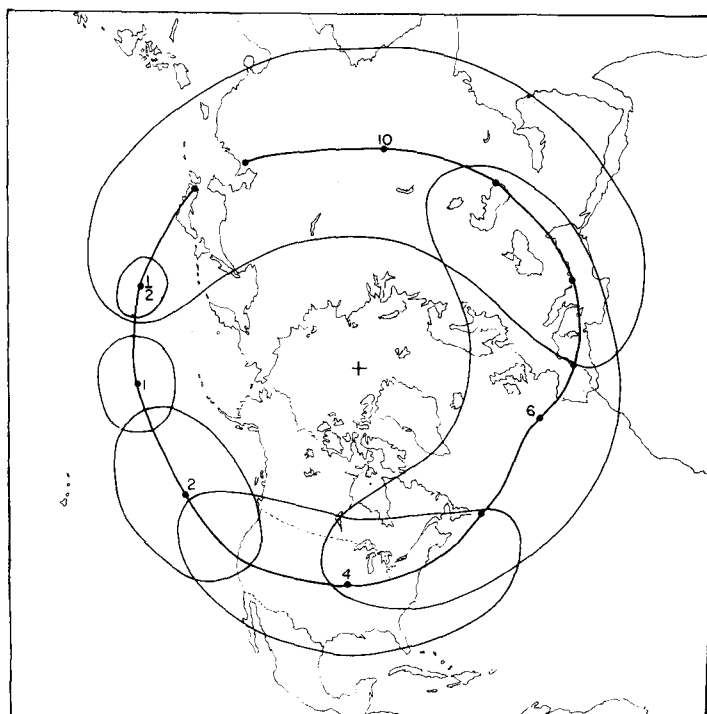


FIGURE 5.—Ellipses delineating the areas within which observations and computations indicate 50 percent of the transosondes are to be found a given number of days after release from Iwakuni, Japan.

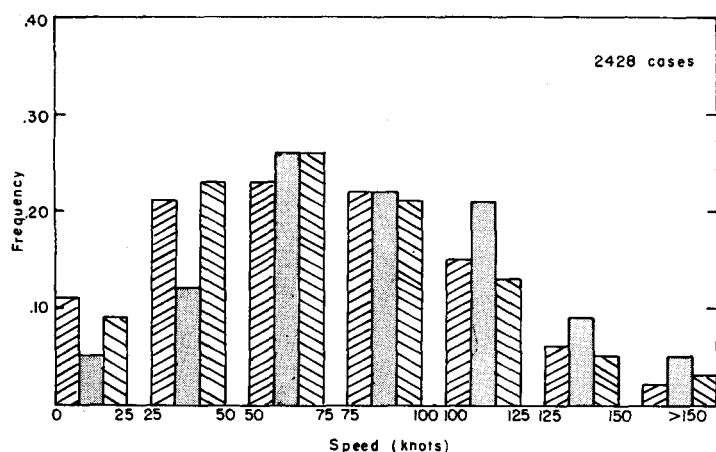


FIGURE 6.—Distribution of 6-hour-average wind speeds obtained from 1957-1959 transosonde flights at 300 mb. and 250 mb. Within each class interval the left hand, middle, and right hand columns give, respectively, the frequencies for flights during fall, winter, and spring.

tudinal (dots) standard deviations as a function of time after transosonde release. The values plotted are the means of the standard deviations (in degrees latitude) determined separately for fall, winter, and spring. The lines in the diagram represent the fit of the indicated analytic expressions to these values. It is seen that the longitudinal standard deviation increases almost linearly with time after release, whereas the latitudinal standard deviation increases more slowly with some evidence for the superposition upon the power variation of a small-scale sinusoidal fluctuation. This sinusoidal fluctuation would be associated with the tendency for latitudinal bunching of the transosondes as they approach the mean trough positions near the east coasts of continents. With the aid of these analytic expressions the standard deviations of position can be estimated for time intervals after transosonde release exceeding 4 days. Figure 5 shows, by means of ellipses, the areas within which these standard deviations indicate 50 percent of the transosondes would be located a given number of days after release from Japan. The ellipses are centered on a mean wintertime trajectory determined from the 1957-59 transosonde flights for the first 4 days following release and from mean 300-mb. maps prepared by Brooks [2] for the remainder of the trajectory. This figure makes more obvious the great dispersion in the longitudinal direction compared with the dispersion in the latitudinal direction when the flights are grouped by season. As a result, 10 days after release it is estimated that the latitudinal extremes of the ellipses would not fall outside the zone of prevailing westerlies, whereas the longitudinal extremes embrace all of Eurasia. On the basis of earlier transosonde flights, launched from Minneapolis, Minn., and Japan, Edinger and Rapp [3] found larger latitudinal and smaller longitudinal standard deviations of position as a function of time after release than found here.

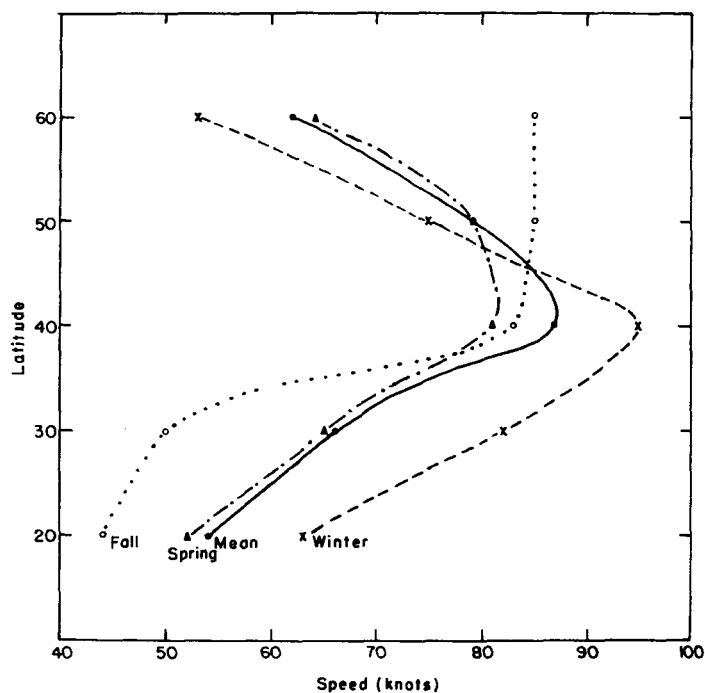


FIGURE 7.—Transosonde-derived wind speed as a function of latitude for the three seasons and the mean of all flights.

4. MAGNITUDE OF VELOCITY AND AGEOSTROPHIC VELOCITY

Transosonde-derived wind speeds were obtained from distances between smoothed transosonde positions 6 hours apart. The smoothed positions were obtained by the averaging of three successive latitude and longitude determinations 2 hours apart. Figure 6 shows the distribution by season of the 6-hour-average wind speeds so obtained. For all three seasons the speed mode is 50-75 knots. However, in winter 35 percent of the wind speeds exceed 100 knots whereas in fall and spring only about 23 percent of the speeds exceed this value. In winter 5 percent of the speeds exceed 150 knots. This percentage would doubtless be higher except for the considerable reduction in peak wind speeds brought about by the use of 6-hour-average winds derived from smoothed positions.

Figure 7 shows the transosonde-derived wind speed as a function of latitude for the three seasons and the mean of all flights. In the mean the wind speed is shown to be a maximum just north of latitude 40°. Rather surprisingly, during the fall the transosonde-derived wind speeds are strongest far to the north. It must be remembered, however, that since the transosondes were launched from a single location, they were sampling ridge conditions in the north and trough conditions in the south. Since it has been found from the transosonde flights that in the average the speed is stronger on ridges than in troughs (fig. 11), a bias easily may be introduced. Along this line, it may be noted that in winter the transosonde-derived wind speed is a maximum considerably north of latitude

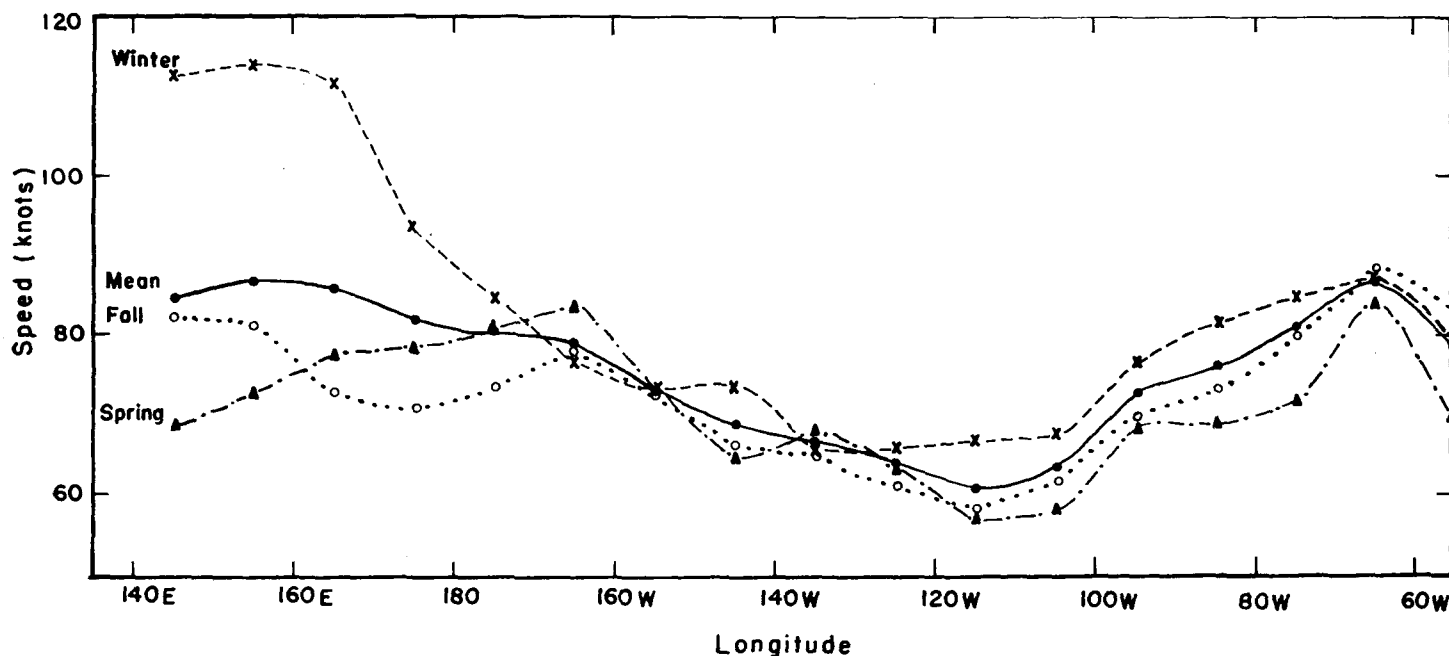


FIGURE 8.—Transosonde-derived wind speed as a function of longitude for the three seasons and the mean of all flights.

30° where the zonal geostrophic wind apparently has its hemispheric maximum [4]. This could be a result of a geostrophic wind bias (wind in the trough always subgeostrophic), the fact that the transosondes sample ridges at latitude 40° and troughs at latitude 30°, or a geographical bias due to the comparison of winds over a portion of the hemisphere with winds around the entire hemisphere.

Figure 8 shows the transosonde-derived wind speed as a function of longitude for the three seasons and the mean of all flights as determined over a limited latitude range. Impressive is the magnitude of the wind speed just to the east of Japan during the winter. However, in spring the maximum wind speed is located near 165° W. rather than near Japan. It is of interest that from 180° longitude to the west coast of North America the wind speed is nearly the same during all three seasons, whereas the diagram illustrates the well-known fact that over North America the wind speed is greater in winter than in fall or spring.

Figure 9 gives the distribution of 12-hour-average "natural" ageostrophic components obtained from the 2 years of transosonde flights. These components were evaluated through the equations of motion utilizing accelerations derived from transosonde velocity changes in 12 hours. The exact manner in which these cross-contour ($V \sin i$) and along-contour ($V \cos i - V_g$) components of the ageostrophic wind are obtained from transosonde data is reported in [5]. For both ageostrophic components the mode is 0–5 knots while about 4 percent of the cross-contour and 15 percent of the along-contour components of the ageostrophic wind exceed 25 knots. In the mean, the cross-contour component of the ageostrophic wind is about two-thirds the magnitude of the

along-contour component. From comparison of the average values of these ageostrophic components with the values of the wind speed shown in figure 6, it is estimated that in the average the ageostrophic wind is nearly one-fourth the magnitude of the wind itself.

Of importance in the study of the meridional momentum flux is the product of zonal-meridional wind components and their geostrophic and ageostrophic parts. Since zonal and meridional ageostrophic velocity components are easily obtained from zonal and meridional components of transosonde acceleration, the transosondes offer a feasible means for evaluating the contribution of ageostrophic winds to the meridional transport of momentum. Table 1 gives the mean seasonal values for the products of interest. The mean value of the zonal-meridional wind product for the 2 years of data is 310 kt.², corresponding to a mean correlation between zonal and meridional wind components of 0.21. Integrating around the hemisphere at latitude 35° N. during January, Mintz [6] found an average (geostrophic) value of 285 kt.². Especially noteworthy in table 1 is the sum of the products involving ageostrophic terms, as shown in the next to the last column. These sums are almost 10 percent of the wind products

TABLE 1.—Magnitude of zonal-meridional wind and geostrophic-ageostrophic wind products derived from 2 years of transosonde flights (kt.²)

| | $\overline{u^2}$ | $\overline{u_g^2}$ | $\overline{u_{ag}^2}$ | $\overline{u_{ag}^2}$ | Sum of ageostrophic products | Cases |
|-------------|------------------|--------------------|-----------------------|-----------------------|------------------------------|-------|
| Fall..... | 284 | 2 | 29 | —9 | 22 | 611 |
| Winter..... | 260 | —11 | 3 | —20 | —28 | 743 |
| Spring..... | 393 | 41 | 32 | —49 | 24 | 637 |
| Mean..... | 310 | 12 | 21 | —26 | 7 | 1991 |

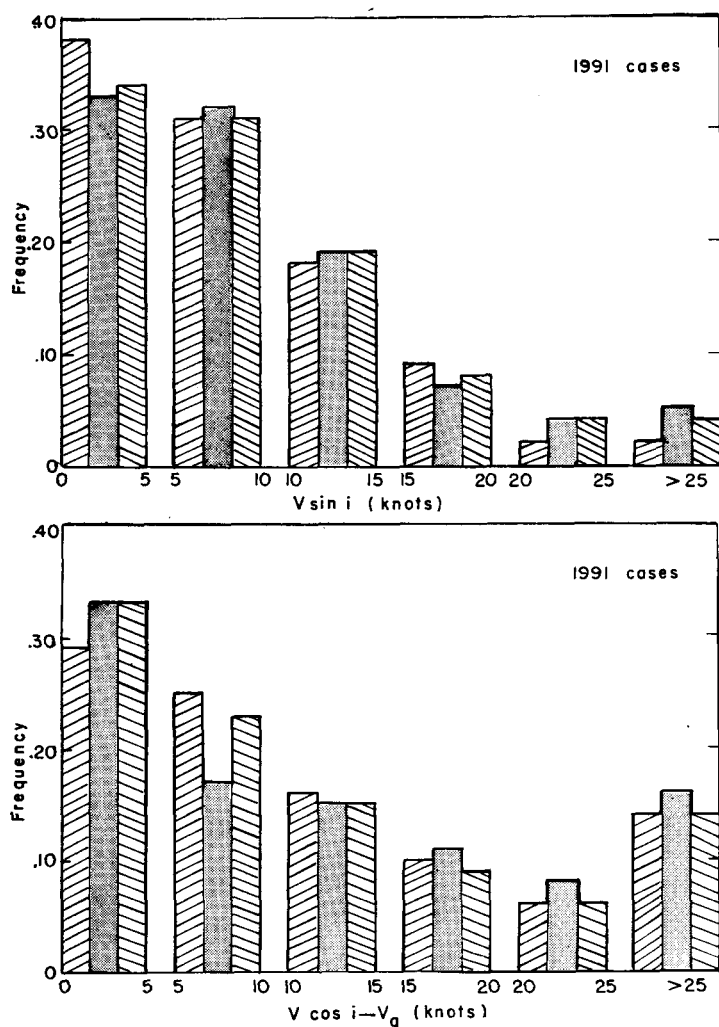


FIGURE 9.—Distribution of 12-hour-average cross-contour ($V \sin i$) and along-contour ($V \cos i - V_g$) components of the ageostrophic wind obtained from 1957–1959 transosonde flights at 300 mb. and 250 mb. Columns indicate frequencies for fall, winter, and spring, from left to right as in figure 6.

themselves and suggest that in winter the ageostrophic products counteract the northward meridional flux of momentum associated with the geostrophic winds whereas in fall and spring they augment this flux. This result may be associated with the seasonal shift of the jet stream as suggested by the theoretical work of Lorenz [7].

5. PERIODICITIES AND CORRELATIONS FOR VELOCITY AND AGEOSTROPHIC VELOCITY PARAMETERS

A crude estimate of the predominant periodicity in the fluctuations of velocity and ageostrophic velocity parameters was obtained by multiplying by two the length of time for which the deviation of the parameter from the mean value for the flight maintained the same sign. For example, if the meridional wind component were positive

TABLE 2.—Correlation coefficients among velocity and “natural” ageostrophic velocity components based on 2 years of transosonde flights

| Correlation between: | Fall | Winter | Spring | Mean |
|---|-------|--------|--------|-------|
| Zonal and meridional wind | 0.258 | 0.135 | 0.288 | 0.211 |
| Zonal wind and along-contour component of ageostrophic wind | .236 | .055 | .085 | .113 |
| Meridional wind and cross-contour flow | .321 | .136 | .056 | .138 |
| Cross-contour flow and along-contour component of ageostrophic wind | -.040 | .003 | -.057 | -.025 |
| Cases | 611 | 743 | 637 | 1991 |

(south wind) for three successive 6-hour time intervals, the period would be entered as 36 hours. It should be noted in passing that errors in transosonde positioning will tend to introduce a 12-hour periodicity in the transosonde velocity, as determined here, and a 24-hour periodicity in the ageostrophic wind, as determined here.

Figure 10 shows the results obtained by this method for the meridional velocity component and the two “natural” ageostrophic components. The meridional wind fluctuates most frequently with a period of about 41 hours, which indicates the most frequent time needed for a 300-mb. or 250-mb. transosonde to transit a long wave in the westerlies. The cross-contour component of the flow ($V \sin i$) fluctuates most frequently with a period of about 23 hours. It is not certain, however, to what extent this represents a real periodicity in this component since, as mentioned above, an error in transosonde positioning would introduce such a period of fluctuation. Further work along this line using ageostrophic components averaged over a shorter time interval is indicated, since the inertial period corresponding to the mean latitude about which the transosondes oscillated is 20 hours and thus we may have evidence here for inertial oscillations. The along-contour component of the ageostrophic wind fluctuated most frequently with a period of about 30 hours as if reflecting both the long-wave period of 41 hours and the cross-contour-flow period of 23 hours. Similar computations were carried out for the zonal wind component and the wind speed but they are not presented here since they showed no pronounced short-period fluctuation, perhaps due to the fact that the deviations from the mean for these parameters reflect the long-period (4 days or more) periodicity in the transosonde wind associated with the passage of the transosonde from the region of strong winds over Japan to the region of strong winds over the northwestern Atlantic (fig. 8).

Table 2 shows the correlation coefficients among certain velocity and ageostrophic velocity parameters for the season and the mean of all flights. According to the “Z test” presented in Hoel [8], with the number of cases here available, a correlation of 0.05 is significant at the two-sigma level in the mean and a correlation of 0.08 is significant at the two-sigma level for the seasonal data.

As would be expected, the zonal and meridional wind components are significantly positively correlated in all three seasons with the correlation most pronounced in fall

and spring. The zonal wind and along-contour component of the ageostrophic wind are positively correlated in all three seasons (fall and spring significant) as are the meridional wind and the cross-contour component of the ageostrophic wind (fall and winter significant). The correlation between the two ageostrophic wind components is negative in fall and spring and slightly positive in winter, but none of the correlations is significant. Since, along an idealized wave-shaped trajectory, the meridional wind component would be a maximum at the pre-trough inflection point and the along-contour component of the ageostrophic wind would be a maximum at the trajectory crest, the relative magnitudes of the above correlations yield estimates of where in the wave-shaped flow pattern the maximum zonal wind and maximum flow toward low pressure occur on the average. Based on such reasoning, figure 11 shows that during all three seasons the maximum zonal wind is located about halfway between pre-trough inflection point and trajectory crest while the maximum flow toward low pressure occurs near the pre-trough inflection point, with some doubt as to whether it occurs just upstream from or just downstream from this point.

6. ESTIMATION OF THE MEAN TRANS-PACIFIC MERIDIONAL FLOW

The existence of a mean meridional cell in the Tropics (Hadley Cell) has been confirmed by wind measurements and estimates of the angular momentum balance. However, the sense, or even existence, of a meridional cell in temperate latitudes (Ferrel Cell) is still in dispute. It is shown below how the changes in height of a constant-pressure surface at successive transosonde positions permits the estimation of the mean meridional flow over a limited portion of the hemisphere.

The change in height of a constant-pressure surface along a transosonde trajectory can be estimated according to the equation

$$\Delta z = \int_{t_1}^{t_2} \frac{\partial z}{\partial t} dt - \frac{V_2^2 - V_1^2}{2g} - \frac{1}{g} \int_{t_1}^{t_2} Vw \frac{\partial V}{\partial z} dt \quad (1)$$

where Δz is the height change following the transosonde, $\partial z/\partial t$ is the local height change along the trajectory, V_2 and V_1 are transosonde speeds at two different times t_2 and t_1 , g is the acceleration of gravity, w is vertical air motion, and $\partial V/\partial z$ is vertical wind shear [9]. The term involving the local height change may be large on individual flights, but since it is not likely to have an average much different from zero for flights released almost randomly from Japan, it will be set equal to zero in this discussion. Moreover, while the term involving the vertical velocity may be important along isolated trajectory segments, it was found to be of negligible magnitude in the mean for many flights due to the very small value for the trans-Pacific vertical velocity determined by the adiabatic method ($0.1 \text{ cm. sec.}^{-1}$).

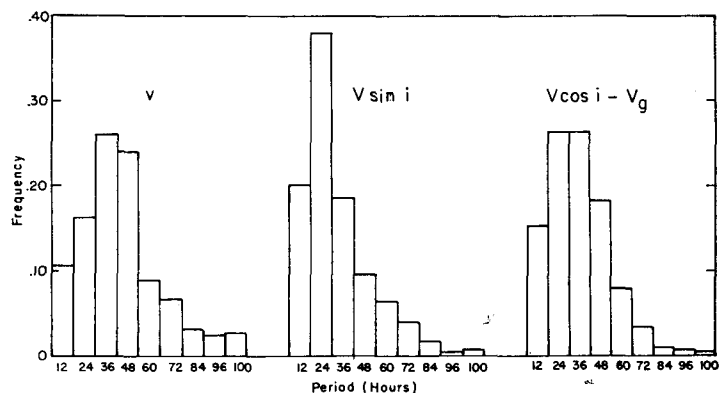


FIGURE 10.—Distribution of periods of fluctuation for meridional wind component (v), cross-contour flow ($V \sin i$), and along-contour component of ageostrophic wind ($V \cos i - V_g$).

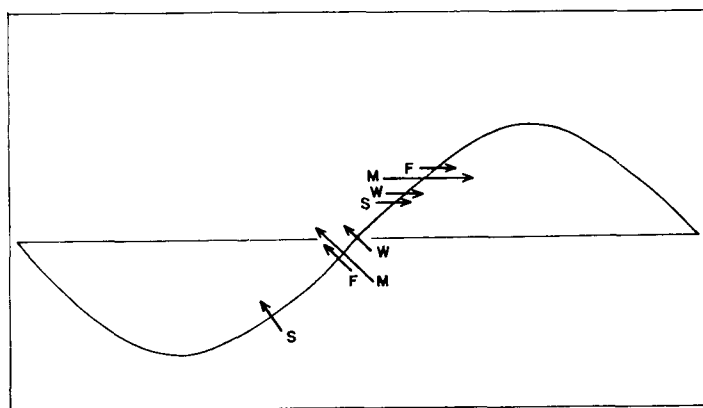


FIGURE 11.—Positions along schematic wave-shaped trajectory of maximum zonal wind (horizontal arrows) and maximum flow toward low pressure (arrows normal to trajectory) for fall (F), winter (W), spring (S), and the mean (M) of all flights.

The top row in table 3 gives the change in height of the constant-pressure surface between Iwakuni and the place where the transosonde transits 120° W. longitude which would be expected due to the change in speed along the individual transosonde trajectories (middle term in equation (1)). Since the transosondes slow down while crossing the Pacific, one would expect the height of the constant-

TABLE 3.—Computed and observed trans-Pacific height changes (in feet) of constant pressure surfaces along transosonde trajectories and derived mean meridional ageostrophic flow

| | Fall | Winter | Spring | Mean |
|--|------|--------|--------|------|
| Height at 120° W. minus height at Iwakuni derived from change in transosonde speed..... | 170 | 450 | 180 | 290 |
| Height at 120° W. minus height at Iwakuni obtained from 300 mb. and 250 mb. NAWAC maps..... | -390 | 220 | -100 | -50 |
| Height discrepancy in radiosondes (Japanese minus United States)..... | 130 | 130 | 130 | 130 |
| Observed height difference minus computed height difference..... | -430 | -100 | -150 | -210 |
| Derived mean meridional flow (knots)..... | 3.1 | 0.9 | 1.2 | 1.6 |
| Number of evaluations..... | 27 | 40 | 27 | 94 |

pressure surface at the transosonde position at 120° W. to be higher than the height over Iwakuni at the time of transosonde release, as shown in the top row of table 3. The second row in table 3 gives the average observed height difference between Iwakuni and the place where the transosonde transits 120° W. as obtained from NAWAC maps. It is most surprising that in the mean the height at Iwakuni is greater than that at 120° W. in complete contradiction with what would be anticipated from the change in transosonde speed. In the mean for all flights the discrepancy between what is observed and what would be computed from the middle term in equation (1) is 340 feet. Part of this discrepancy is due to the incompatibility of United States and Japanese radiosondes, as found at Payerne and reported by Harmantas [10]. According to the Payerne tests, the Japanese 300-mb. and 250-mb. heights should average about 130 feet more than those reported by United States radiosondes. Since the existence of a mean floating level for the transosondes slightly above the constant-pressure surface in question was found to have no influence on the above calculations, unless the incompatibility of Japanese and United States radiosondes is greater than determined at Payerne, the above data suggest the presence of a mean northward ageostrophic flow at 300 mb. and 250 mb. above the Pacific Ocean of magnitude given by the next to the last row in table 3. These meridional velocity components in table 3 were evaluated by determining the meridional displacement corresponding to a given pressure-height change based on the average meridional distance between 300-mb. and 250-mb. contours as estimated from the zonal component of transosonde velocity. Since it is not known what transosonde flights over the remainder of the hemisphere would yield with respect to the sense and magnitude of meridional ageostrophic flow, the resolution of the meridional-cell problem awaits the extension of the flights to Eurasia.

7. TRANSOSONDE DENSITY AS A FUNCTION OF TIME AFTER RELEASE

For the purpose of studying the transosonde density a given number of days after release for transosondes released from the same point at different times, the number of transosonde pairs at various distances apart was determined by season for the 1957–59 transosonde flights from Japan. The approach resembles Richardson's distance-neighbor technique except that, instead of determining the temporal variation of the distance separating pairs of air parcels in the air at the same time, here we determine the variation with time since release of the distance separating pairs of transosondes in the air at different times. Certainly results obtained utilizing data of the latter type need not be representative of the results which would be obtained using data of the former type.

Figure 12 shows the percentage of possible transosonde pairs which were located (within 5-degree latitude bands)

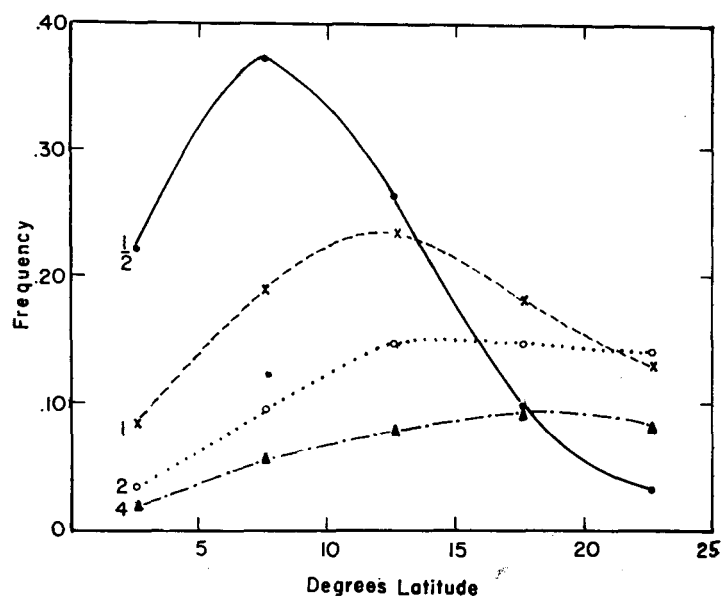


FIGURE 12.—Distribution of distances between all possible transosonde pairs as a function of time in days after their (non-simultaneous) release.

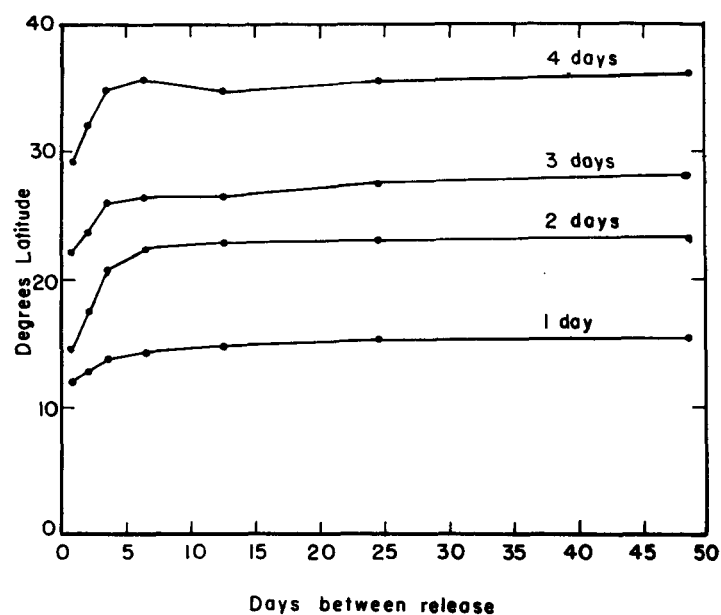


FIGURE 13.—Average geographical distance between all possible transosonde pairs a given number of days after release as a function of time interval between release of transosondes making up the pair (abscissa).

a given number of degrees latitude apart a certain number of days after release from Japan, as obtained by averaging the results derived for the three seasons of fall, winter, and spring. This diagram shows, for example, that 1 day after transosonde release 23 percent of the possible transosonde pairs are 10° – 15° latitude apart, while 4 days after transosonde release 8 percent of the possible pairs are separated by this distance. With an average error in

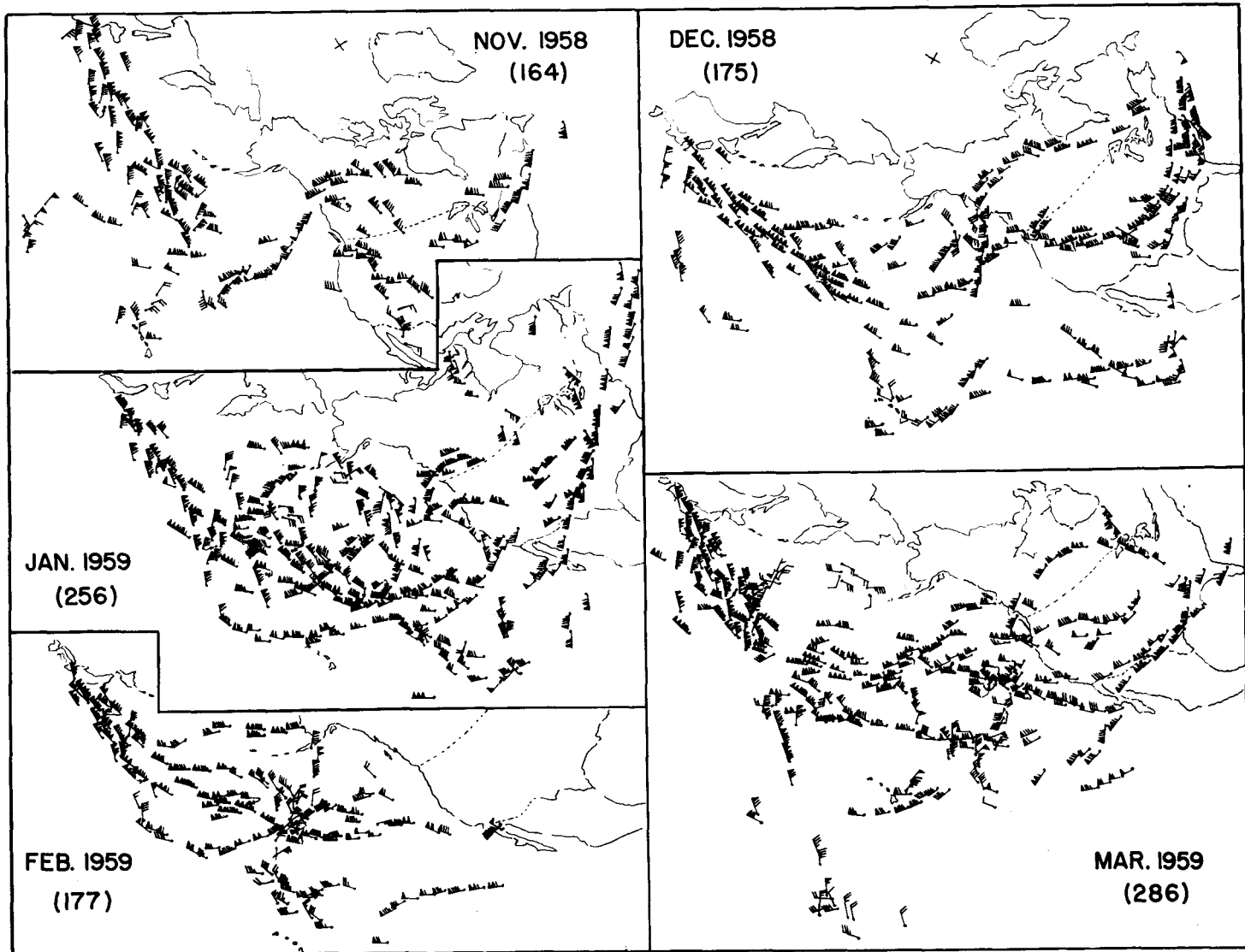


FIGURE 14.—Transosonde-derived winds plotted on NAWAC 250-mb. maps between November 1958 and March 1959. Numbers in parenthesis give the total plottings for each month.

percentage of 0.03 in the 20 plotted positions given in figure 12, the percentage of possible transosonde pairs (P) separated by a given number of degrees latitude (R) a given number of days after release from Japan (t) is given analytically by

$$P = 40 t R^{-2.2} e^{\frac{-25t}{R^{1.2}}} dR \quad (2)$$

where dR is the latitude interval under consideration (5° in fig. 12).

Differentiating equation (2) with respect to R and setting the resultant equal to zero it is found that the most frequent distance (mode) between balloon pairs (R_m) is given by

$$R_m = 8.8 t^{0.833} \quad (3)$$

where t is in days and R_m is in degrees latitude. Thus,

7 days after transosonde release it is estimated that the most frequent separation of pairs of transosondes would be 45° of latitude with, from equation (2), 11 percent of the possible transosonde pairs being separated by 40° – 50° latitude. It is interesting that, with the replacement of the time coefficient in equation (3) by the value 5.8, this equation almost exactly satisfies the average distance between 700-mb. geostrophic-trajectory pairs initiated from a point at 2-day intervals (similar to the transosondes) during the period April–June 1948, as reported in a paper by Durst et al. [11]. Thus there is independent evidence in support of the power of the time given in equation (3). Theoretical considerations presented by Durst et al. indicate that, if it is assumed that the autocorrelation coefficient is exponential in form, the average distance between trajectory pairs should increase nearly linearly with time initially and increase according to the square root of time

two or more days after initiation. If anything, the experimental results suggest a quicker trajectory separation with time than does the theory based upon the assumption of an exponential form for the autocorrelation coefficient.

Integrating equation (1) with respect to R it is found that the percentage of possible transosonde pairs separated by less than the distance R (P_R) is given by

$$P_R = \frac{4}{3} e^{\frac{-25R}{R^{1.2}}} \quad (4)$$

Thus, 7 days after transosonde release it would be estimated that 27 percent of the transosonde pairs would be separated by less than 50° latitude or, conversely, that 73 percent of the transosonde pairs would be separated by more than this amount.

The above equations are not exact since the average distance between the elements of a transosonde pair increases with the time interval (T) between the release of the transosondes making up the pair (fig. 13). However, if the transosondes are released more than 6 days apart there is little increase in the average separation as a function of time between release. Since the results presented in figure 12 are based upon seasonal data, the average interval between the release of the components of a transosonde pair is 45 days. If the transosondes had been released in quick succession so that the interval between transosonde release was, in the average, only 2 days say, then a larger percentage of the transosonde pairs in figure 12 would be separated by smaller distances.

The above analysis has application to "silent area" problems. For example, suppose that a pathfinder balloon was at a certain geographical location 2 days after release and it was desired to know the probability of getting another balloon, launched from the same site, within 10° latitude of this location 2 days after release. According to figure 12 there would be only a 13 percent chance of getting a balloon within the desired area unless the additional balloons were released soon after positioning of the pathfinder balloon, in which case the probability might jump to 15 percent or so. Thus, if seven or eight additional balloons were released, in the average it would be expected that one of these balloons would be within the required area 2 days after release. For further extension in time and space reference may be had to equation (4). For example, this equation would suggest that in order to get a second balloon within 50° latitude of the pathfinder balloon 7 days after release, on the average four additional balloons would have to be released.

8. THE USEFULNESS OF TRANSOSONDE DATA FOR OPERATIONAL WEATHER ANALYSIS

Between November 1958 and April 1959, 6-hour-average transosonde-derived winds were included in the transosonde teletypewriter messages originating at Pearl Harbor, Hawaii and Norfolk, Va. These winds were plotted in a

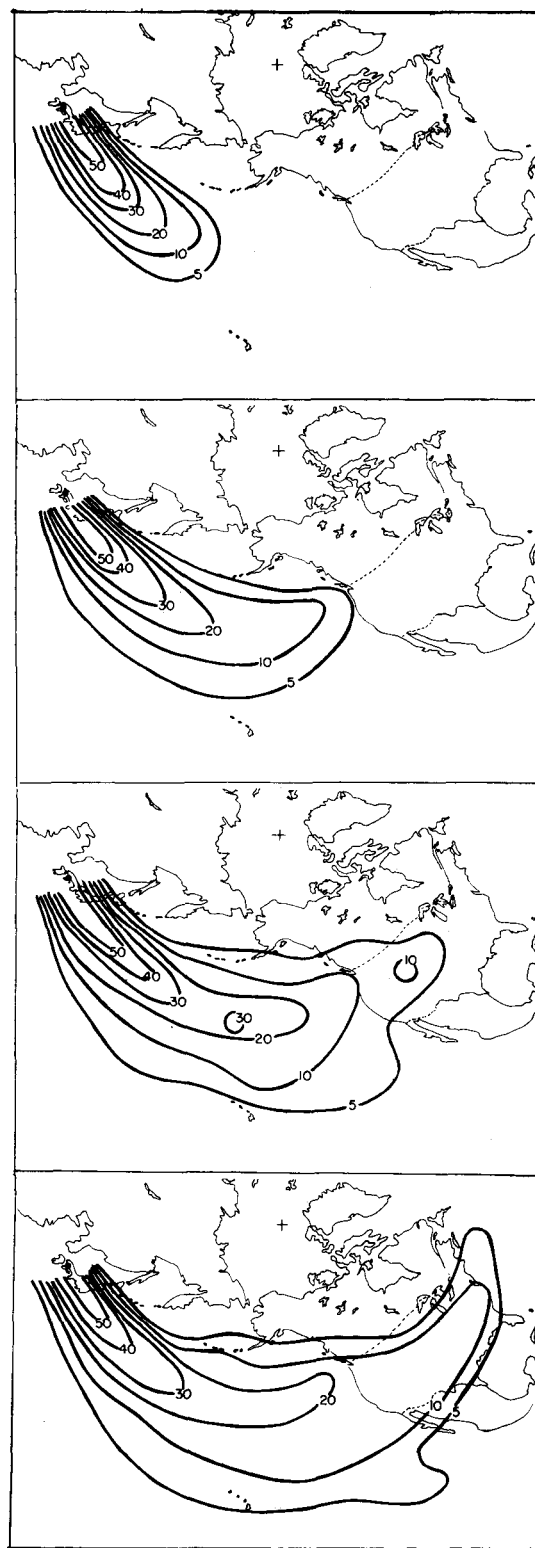


FIGURE 15.—Percentage of 1957–1959 transosondes at 300 mb. and 250 mb. passing through 5-degree latitude-longitude "boxes" within (from top to bottom) one, two, three, and four days following release.

routine fashion upon the NAWAC 250-mb. maps. Figure 14 shows the winds so plotted during five of these six months. A total of more than 1000 transosonde-derived winds was plotted during this 5-month interval, providing a rich source of information for the map analyst and forecaster. Since the tracking, communications, and plotting procedures were only operating at 50 percent efficiency during this time, twice as many winds could have been derived from the flights. For the planning of any future transosonde operation it is desirable to know what percentage of the time a transosonde released from Iwakuni would pass over a given geographical region and provide meteorological data there. Based on the 1957-1959 transosonde flights at 300 mb. and 250 mb., figure 15 shows the percentage of transosondes released which transited 5-degree latitude-longitude "boxes" within a certain number of days following release. This diagram shows, for example, that one-tenth of the transosondes released from Iwakuni would within 3 days following release, furnish meteorological information within the 5-degree latitude-longitude "box" embracing most of Wyoming. It may be noted that the highest percentages are found in just that latitude belt of the Pacific Ocean where conventional upper-air data are almost totally lacking. It seems certain that transosonde releases from Iwakuni, Japan could provide the means for obtaining much-needed upper-wind and other data over the Pacific Ocean.

9. CONCLUSION

Transosonde flights yield data of importance from both the operational and research viewpoint. Part of this importance resides in the ability of the transosondes to fill in the climatological void in regions where conventional upper-air data are sparse, such as the Pacific Ocean area. In this paper we have intentionally presented climatological data in the Lagrangian frame of reference with the hope that the meteorologist and climatologist may thereby come to realize that the Eulerian-type data now used exclusively is not the only type of data available and, indeed, is perhaps not the type of data which is most desirable. It may well be that a change in emphasis from

Eulerian to Lagrangian-type data is the step needed to achieve a higher plateau of knowledge in the field of meteorology. The transosonde system offers the means by which this change in emphasis can be made a reality.

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